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## Considerations for States to Implement National Nuclear Forensics Libraries (NNFL)

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### **ABSTRACT**

Beginning with the breakup of the Soviet Union in the 1990s, seizures of illicit nuclear materials have created widespread concern over the possibility, however remote, of illicit trafficking leading to a non-state actor or rogue nation acquiring sufficient nuclear material to assemble an improvised nuclear device (IND). The need to determine the origin of nuclear material outside of regulatory control has led to a growing international consensus about the importance of identifying and characterizing nuclear materials. By identifying the process history, intended use, and production location for all nuclear materials within a state, and compiling that information in a nuclear forensic library, states are left with a strong mechanism to help combat illicit nuclear trafficking both domestically and as partners in a coordinated international effort.

To develop an NNFL, states would collect and validate data on domestic nuclear materials. If a nuclear material interdiction occurs and is determined to be international in nature, i.e., the material is inconsistent with domestic production, the state could utilize a national point-of-contact to engage other states and the International Atomic Energy Agency (IAEA) regarding the source of the material.

The IAEA has provided guidance on collecting and organizing information about nuclear materials based on nuclear fuel cycle stages as a context for material comparisons, but not on how much effort a state may have to expend to construct an NNFL. In this study, states are placed into groups based on the extent of their fuel cycle development to estimate the effort to develop an NNFL. Groups are arranged from the standpoint of the nuclear fuel cycle and associated nuclear materials inventories to provide a better understanding of the effort to create an NNFL. This work does not provide an exact breakdown of the effort for any particular country but rather identifies the factors that directly influence the level of effort each group will need to develop an NNFL.

### **INTRODUCTION**

Driven by law enforcement needs to determine the origin of seized nuclear material since the early 1990s and concern that a non-state actor or terrorist group could acquire enough material to assemble an IND, growing international consensus to identify and characterize nuclear materials for nuclear forensics has arisen. By identifying the material process history, the original intended use, the production location and compiling that information in a nuclear forensic library, states create strong mechanisms to combat illicit nuclear trafficking. Additional information in an NNFL may include how the material arrived at the point of interdiction.

There are two potential models for nuclear forensics libraries, an international nuclear forensics library (INFL) and a national nuclear forensic library (NNFL), both with advantages and disadvantages. While an INFL would build a strong system of material protection, control, and accounting (MPC&A) and a set of characteristics to be included in a central database (potentially held by the IAEA), an INFL would carry with it problems associated with international access to the data. Widespread reluctance among states to share data on their nuclear materials for both national security and economic reasons makes adoption of this model unlikely.

With an NNFL each state would collect and validate data on their domestic nuclear materials and, in the event of an interdiction, i.e., states would utilize a single national point-of-

contact to query other states regarding the material. In this model, the IAEA could potentially act as an intermediary or coordinating organization. Benefits of NNFLs include: providing a centralized data set capturing nuclear material characteristics; establishing and maintaining a systematic way to process and update domestic nuclear material inventories; a framework for nuclear forensic activities and cooperation; the absence of a requirement to divulge sensitive or proprietary nuclear material characteristics; and international confidence a country could accurately identify interdicted nuclear material.

### **PURPOSE AND SCOPE**

The creation of NNFLs has been supported by the IAEA<sup>i</sup>, the Global Initiative to Combat Nuclear Terrorism (GICNT)<sup>ii</sup>, and the Nuclear Security Summits<sup>iii</sup>, but development has been difficult, owing largely to questions of the effort and financial capital to construct and maintain NNFLs. The IAEA has provided guidance on collecting and organizing information based on the nuclear fuel cycle stages, as well as a context for material comparisons, but little information on constructing an NNFL.<sup>iv</sup> Questions of constructing a database, establishing a material archive, legal policy, the level of effort required, and the utility of databases compared to perceived level of effort have yet been answered.

We address these questions through the lens of the minimum effort to develop and maintain an NNFL, including considerations a state should take before establishing a library. Once states have established an NNFL, they will be encouraged to share experiences, database templates and structures, and develop best practices to articulate guidelines other states may follow. This approach does not create a final model for NNFLs; rather, it attempts to stimulate further dialogue on the information that should be included, how the information/data should be structured, and the level of effort to develop NNFLs worldwide.

### **A GRADED APPROACH TO NNFLs**

To determine the above-mentioned factors, we create six groups based primarily on the maturity of the domestic nuclear fuel cycle (Table 1). Each group represents capabilities listed according to the IAEA Nuclear Fuel Cycle Information System and IAEA Research Reactor Database System. Group 1 will not be addressed as the effort to develop a model database for characterization of radiological sources has been developed outside the DOE/NNSA<sup>1</sup>. The essential elements of this approach are described in greater detail below. It is important to note that each Group is not all encompassing, i.e., Group 6 does not include all the elements considered in Groups 2-5, but may include elements of other groups such as conversion, fuel fabrication, and reprocessing. Furthermore, rather than only examining the current nuclear fuel cycle and associated nuclear materials, we consider the state a whole, including historical and legacy nuclear fuel cycle capabilities and associated materials. Examples of materials that could be included in each group's nuclear fuel cycle are presented in Table 2.

**Table 1: Categories of NNFL candidate states<sup>v</sup>**

Group 1 <sup>2</sup>	Group 2	Group 3	Group 4	Group 5	Group 6
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<sup>1</sup> Goldberg, Margaret, and Martha Finck. "International Data on Radiological Sources." Institute for Nuclear Materials Management. July 2010. <http://www.inl.gov/technicalpublications/Documents/4633185.pdf>.

Countries with radiological source holdings; little to no nuclear fuel cycle or forensics capabilities	Countries with Group 1 capabilities + geological disposition, mining, milling	Countries with Group 1 capabilities, at least one research reactor and/or nuclear power plant and associated nuclear waste and spent nuclear fuel (SNF)	Countries with Group 3 capabilities + fuel fabrication, (and/or) conversion, and R&D activities	Countries with Group 4 capabilities + enrichment, (and/or) reprocessing, (and/or) mixed oxide (MOX) capabilities	Countries with Group 5 capabilities + current or previous weapons programs
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**Table 2: Nuclear Fuel Cycle Stages and Associated Materials<sup>vi</sup>**

NUCLEAR FUEL CYCLE STAGES	EXAMPLE MATERIALS
<b>1. Geologic Deposition</b>	Ore, ore body
<b>2. Uranium Mining, Milling, and Extraction</b>	Ore concentrate, yellow cake
<b>3. Uranium Conversion</b>	UF <sub>6</sub> , UF <sub>4</sub> , UO <sub>2</sub> , U <sub>3</sub> O <sub>8</sub> , uranium metal and alloys
<b>4. Uranium Enrichment</b>	UF <sub>6</sub> , UF <sub>4</sub> , UCl <sub>4</sub> , uranium metal
<b>5. Uranium Fuel Fabrication</b>	UO <sub>2</sub> , U <sub>3</sub> O <sub>8</sub> , pellets, rods/plates, scrap
<b>6. Mixed Oxide (MOX) Fuel Fabrication</b>	MOX powder, pellets, rods, scrap
<b>7. Fresh Nuclear Fuel</b>	Fuel assemblies
<b>8. Irradiated (Spent) Nuclear Fuel</b>	Spent fuel
<b>9. Reprocessing</b>	Plutonium nitrate, uranyl nitrate, plutonium oxide, uranium oxide, mixed oxide, other actinides
<b>10. Radioactive Waste Processing, Handling and Storage</b>	Radioactive waste forms

### ***MEDTHODOLOGY FOR THE DEVELOPMENT OF AN NNFL***

An NNFL is a collection of information relevant to nuclear forensic investigations, including the manufacturer/producer of nuclear materials within a state. An NNFL ideally should include one or more databases and a sample archive. When constructing an NNFL, states need to develop policies that govern the NNFL. These policies should include, but not be limited to:

- the collection and protection of sensitive information;
- information sharing within the state and with foreign states; and,
- NNFL querying.

The development of an NNFL begins by identifying and organizing existing nuclear material information from relevant stages throughout the nuclear fuel cycle. Much of this information may already be found in a state's registry and production records for nuclear material, or from other sources. Once this material has been surveyed, a state should begin mapping the entire fuel cycle, facilities that store and/or ship/receive nuclear materials, and associated facilities with the ability to conduct nuclear material analyses. In most states this process will not be a 'once through' event, rather the development of an NNFL is on-going, involving surveying, collecting, and organizing information on a state's nuclear material holdings.

NNFLs should be organized to allow a nuclear material database(s) to be easily queried. Nuclear materials should be organized to facilitate queries pertaining to unknown nuclear materials compared to known nuclear materials. An NNFL should also identify the facility or facilities where associated nuclear materials are stored or used, and the history of nuclear material use.

The scale of an NNFL is directly correlated with the size of the fuel cycle and the accompanying nuclear materials, i.e., Group 2 states will have an NNFL significantly smaller

than states in Group 6. The development of a library should be a coordinated effort building on a state's technical expertise and experience with nuclear material.

### ***NNFL ROLES AND RESPONSIBILITIES***

It is important to determine the staff to establish and maintain an NNFL. Several models may be considered. In one, minimizing the financial burden, the NNFL staff will have other responsibilities. Similar to the nuclear forensics capability of a state in relation to the nuclear fuel cycle, the effort to establish and maintain an 'NNFL team' will depend heavily on the sophistication of the nuclear fuel cycle. With increasing sophistication, corresponding to "higher" group number, the need for analytical measurements of nuclear material also increases. The frequency and complexity of these measurements will vary greatly from state to state, should be carried out at regular intervals. This model is most appropriate for Groups 1 - 4. States with more expansive nuclear fuel cycles may consider using full-time staff dedicated to developing and maintaining an NNFL.

The national POC is responsible for initiating and responding to nuclear forensic queries from other states and is responsible for providing information on the government's behalf. The POC could be a single official or a team of knowledgeable officials across relevant agencies. The POC will need to initiate contact with foreign POCs and/or respond to international queries, coordinate with the Library Administrator to ensure the data has been properly received and measurements properly vetted and, finally, liaise with law enforcement personnel responsible for investigating illicit uses of nuclear material.

A Library or Database Administrator is responsible for overseeing and managing the library/database. As an individual or team, the Library Administrator should be familiar with the domestic nuclear fuel cycle, radioisotope production, and nuclear material holdings. The Library Administrator is responsible for identifying and organizing information from nuclear facilities and institutes. If the Library Administrator role is fulfilled by a team, both technical and information technology (IT) staff should be included. If the Library Administrator role is fulfilled by an individual, the individual should be trained by technical and IT staff and have a firm understanding of the NNFL and associated processes to establish and maintain the NNFL. The Library Administrator may need legal agreements, i.e., non-disclosure agreements, to receive information from nuclear material providers.

When developing the scientific and technical staff, a balance between experience, formal education, and on-the-job training is needed. The size of the team will depend on the types and numbers of nuclear material analyses required. States may also wish to take advantage of existing analytical capabilities at academic, national laboratory or commercial institutions.

### ***NNFL DATABASE***

The database is a central and key component of any NNFL and provides a centralized structure in which to store data and information (metadata) that characterize nuclear material holdings within a state and may be used in a forensic investigation.

Steps in the creation of a database include:

- Determine relevant data fields and data relationships
- Create NNFL database architecture
- Create a repository of relevant documents
  - o A document repository provides continuity of knowledge and contains information associated with an NNFL
  - o The NNFL database should reference documents within the document repository
- Populate NNFL database

- Automated data uploading saves time and reduces errors, but requires upfront programming effort and testing
- The NNFL staff should develop guidelines and relevant approaches for data vetting, as much of the data could come from commercial sources never designed to generate data of sufficient quality to support a forensic investigation
- SME vetting of data and metadata
- Develop data querying tools
  - This activity should be coordinated with the Library Administrator
  - A good example of an advanced nuclear forensics query tool is the NNSA's Internet Discriminant Analysis Verification Engine (*iDAVE*) developed and hosted by LLNL. *iDAVE* is a secure web application that allows multivariate statistical comparison of an unknown sample against data contained in the associated Uranium Sourcing Database.<sup>vii</sup>

Two types of databases could be used for collecting data for an NNFL, requiring different levels of effort:

- A “flat file” database uses a single table for data and would be useful in states with less developed fuels cycles and small amounts of material. It does not require a great deal of effort in terms of design but is not as efficient or sophisticated. The flat database may become unmanageable with increasing amounts of data and metadata.
- A relational database contains data logically organized and broken into multiple related tables, eliminating redundancy and improving internal consistency. The modular structure of a relational database facilitates advanced database queries. A relational database requires more specialized knowledge to develop, query, maintain, and modify and would be particularly useful in countries with more advanced nuclear fuel cycles and larger amounts of material.

A number of database software packages are available, with varying levels of capability and complexity. In addition to commercial packages with vendor support, many cost-free options are available, including open source packages and scaled down versions of commercial products. When choosing database software states should consider several variables including:

- institutional support for database, including expertise, software and IT policies;
- the complexity required for the state's need;
- the ease of use and maintenance; and
- vendor support.

#### ***DATA TO BE INCLUDED WITHIN NNFL***

All nuclear materials mined in, residing in, or manufactured in a state should be included in an NNFL.

1. Material Identification and Collection Information – the sample ID is a unique identifier.
2. Analysis Laboratory Information – description of laboratory performing the analysis with analytical details.
3. Material Package and Container Information – description of storage/shipment package.
4. Sample or Item Physical Characteristics – dimensions, color and other physical measurements.
5. Sample or Item Chemical/Isotopic Characteristics – chemical, elemental, isotopic, and other measurements.
6. Sample or Item Morphology – e.g., grain size, shape, aspect ratio.
7. Material Processing and Location History – production, processing and storage history.

## 8. Data Vetting Information – a preliminary checklist for vetting the data.

The IAEA recommends a variety of signatures to build a database for nuclear material identification and attribution.<sup>viii</sup> Based on the type of material, different physical, chemical, isotopic and morphological analyses may be performed.

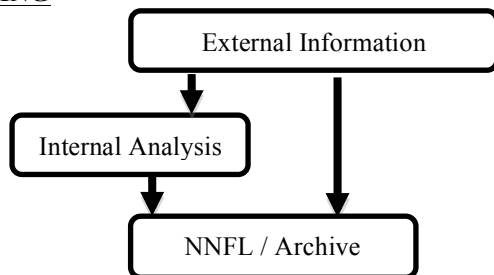
While an NNFL could include different measurements, four are “must have”:

- uranium or plutonium assay;
- major element composition;
- minor trace element composition; and
- uranium and/or plutonium isotopics.

Prior to initiating new analyses, all existing information, including information on legacy materials, should be collected. This information may be available from, *inter alia*, a state’s System of Accounting for and Control of Nuclear Material (SSACs), the IAEA, nuclear regulatory bodies, radiation protection agencies, nuclear research centers, and medical facilities. Although data from in these analyses should be considered, certain limitations may be important. If a state only receives information and not a sample, it has no way to archive the material and will not have the ability for future analysis or testing. The quality (precision, accuracy, detection limit) of the data may also limit its use in a nuclear forensic investigation.

In order to increase the robustness of an NNFL, a state may create and maintain a Nuclear Material Sample Archive, in which material is stored for future analysis. A Nuclear Material Sample Archive should be assembled taking the needs of a state into account and considering a number of pros and cons. On one hand, while a nuclear materials archive would allow a state to validate analytical procedures, train personnel on analytical techniques, and allow for the re-analysis of samples as new techniques and equipment become available, it could create a number of difficulties. A Nuclear Material Sample Archive would compound the cost of an NNFL, potentially pose a radiological hazard, and need a physical security system. States should weigh the positive and negative impacts of a Nuclear Material Sample Archive prior to developing this capability.

### SAMPLE PROCESSING



### ***DESIGN AND STRUCTURE OF AN NNFL***

Prior to developing an NNFL, a State should take a number of preparatory steps:

- identifying the necessary personnel;
- identifying existing information within the state;
- allocating resources for the NNFL; and
- establishing the NNFL structure and the database software.

The IAEA guidance providing a notional structure for an NNFL may not be appropriate for every state as it provides a good starting point but the structure relies on fuel cycle steps, rather than production methods and/or locations.<sup>ix</sup> The IAEA methodology becomes problematic because some nuclear materials appear several times throughout the fuel cycle. In the event of a seizure, the step in the fuel cycle from which material came may not be known and could be difficult to discern. The database should use a material-centered approach rather than a fuel cycle step centered.

Not every state need adopt the same structure for an NNFL; rather, each NNFL should accommodate the needs of the state, the needs of the Library Administrator, and the abilities of the POC. The structure of the NNFL should be based on the range and extent of the nuclear materials within the state; states with more sophisticated nuclear fuel cycles should develop more comprehensive NNFLs and vice versa. States that use nuclear materials but do not produce them could develop an NNFL simply by listing inventories and specifications and relying on suppliers for detailed information.

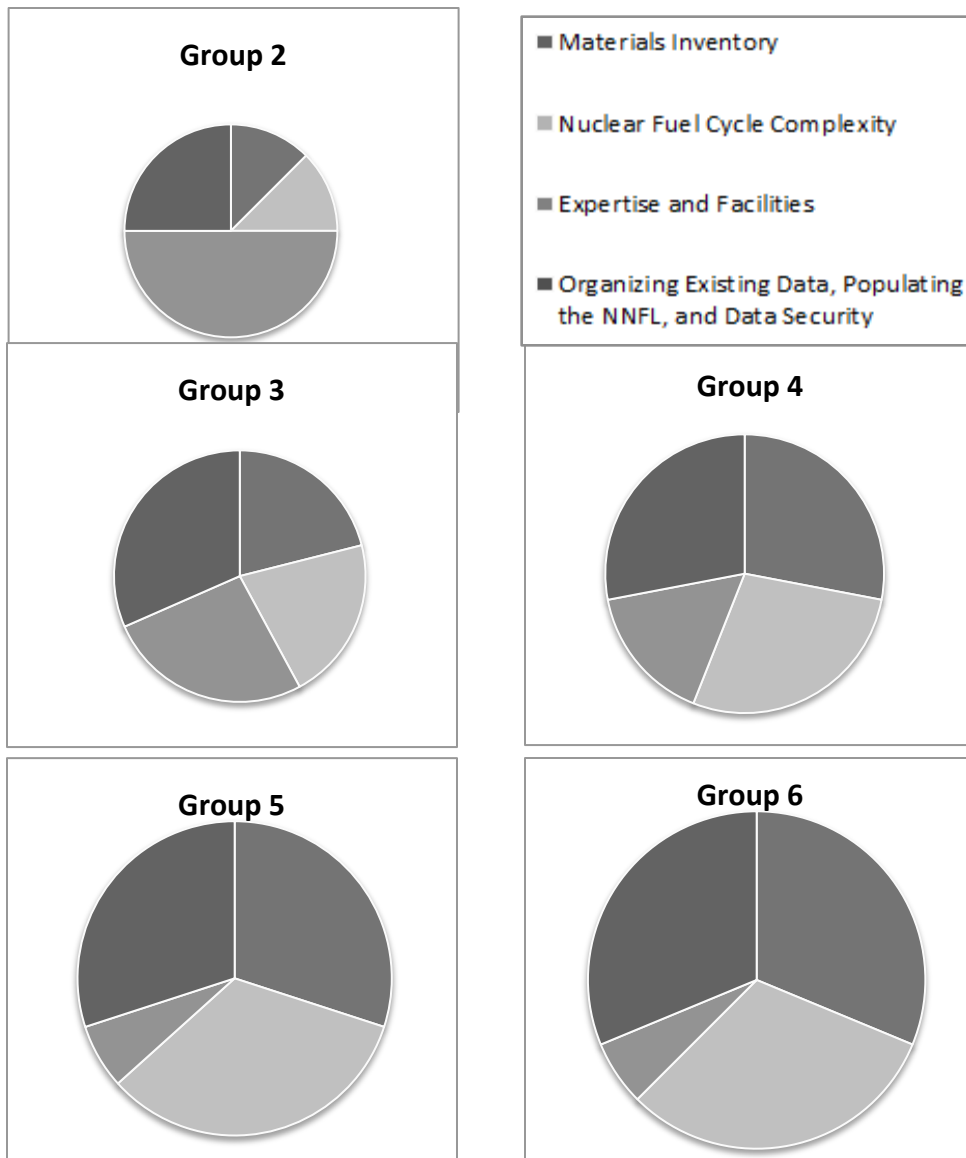
### ***TECHNICAL FACTORS***

There are at least four relevant analytical and technical factors a state should consider before developing an NNFL:

- nuclear fuel cycle maturity and complexity;
- material inventory;
- organizing existing data, populating a database, and data security;
- expertise and facilities; and,
- the availability of existing information.

The breakdown shown below in Fig. 1 is intended to provide a guide for states beginning to design an NNFL, but does not necessarily describe how individual states will choose to organize. The availability of existing information is not included within these graphs as it is not a determining factor; rather it is dependent on the state in question.

**Figure 1: NNFL Factor Breakdown by Group\***



\*

Figures are not to scale.

In Fig. 1 different size circles represent different levels of effort to create an NNFL. For each group the elements of each country represent important considerations. As the diameter of each circle increases, effort also increases, i.e., the diameter for Group 2 is smaller than for Group 6. The distribution of effort also changes within each group, i.e., a Group 2 country will expend less effort to account for its nuclear material than a Group 6 country but will also have less capability to analyze the material. Determining the effort for each group is difficult and the total effort for an individual country should be assessed on a case-by-case basis. Within each groups different countries can use these charts as a basis to better understand the relative effort and judge how best to focus their effort.

#### **ORGANIZING EXISTING DATA, POPULATING THE DATABASE, AND DATA SECURITY**

Much the data within an NNFL may already exist within a state and the state should make every effort to locate and organize these data. The larger the nuclear fuel cycle, the greater the effort the state should expend. The amount of data, as well as its quality, will have a direct effect on the effort, i.e., states that receive but do not produce nuclear materials, as well as states with more information available, may not need a sophisticated capability to analyze samples.

Data security requirements will depend on the nuclear fuel cycle within a state as well as a state's nuclear security policy. States with more sophisticated nuclear fuel cycles possess materials and fuel cycle technologies of greater proprietary and national security concern and require more robust data security. Security will not only need to be monitored more frequently but the system will be more complex, as a larger population may have access to the NNFL.

#### **EXPERTISE AND FACILITIES<sup>3</sup>**

Generally speaking, a state's nuclear fuel cycle capabilities are correlated with the amount of technical expertise, i.e., the larger the nuclear fuel cycle, the larger the technical base. States with larger nuclear fuel cycles have a larger technical and may not require additional analytical equipment. States with smaller nuclear fuel cycles, however, may also have robust technical expertise and analytical capabilities.

#### **AVAILABILITY OF EXISTING INFORMATION<sup>4</sup>**

As mentioned above, prior to beginning analyses, states should collect, organize and evaluate existing information. Within the bounds of commercial sensitivities and legal framework, states should identify, evaluate and organize the data for inclusion in an NNFL. A state may identify materials that have not been analyzed and arrange to have these samples analyzed. Independent verification is always preferred.

#### ***CASE STUDIES***

It is useful to assess each group of states with a specific case study to assess the effort, in terms of time, manpower and financial burden. Factors such as the bureaucracy within a state and nuclear materials holdings are generally assumed to be similar in within a given Group but may vary depending on the nuclear fuel cycle sophistication, i.e., a State with a sophisticated fuel

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<sup>3</sup> **COMPLEXITY OF ANALYSIS VS. DISCRIMINATORY VALUE**

Ideally, an NNFL will contain, at a minimum, information on uranium assay (content), major and minor/trace element composition and uranium and/or plutonium isotope composition for every sample. However, for some states the effort to collect this information or conduct detailed analyses of multiple samples may outweigh the technical ability and/or perceived benefit and, as such, create more of a burden than the state would deem appropriate. If a state deems that it cannot develop an NNFL containing comprehensive information for the above-mentioned properties, the state should emphasize material properties with the highest discriminatory value without putting undue burden on the state. In developing an NNFL, it is most important for each state to implement an NNFL structure that could be most readily utilized in the event of an interdiction.

<sup>4</sup> Sources for information within the state include: mine operators/materials manufacturers/ materials vendors, information from safeguards related activities, nuclear regulatory agencies, radiation protection agencies, and nuclear research centers.

cycle will have more stakeholders within its government and the private sector that could affect the effort to develop an NNFL. Assigning a specific value to each of the above mentioned factors is challenging and makes the level of effort difficult to assess accurately. These factors will directly influence the level of effort for each group of states to develop an NNFL but do not provide a breakdown of the value each factor has in a particular country. Descriptions of three fictional countries belonging to Groups 2, 3 and 4, respectively, are provided as illustrations.

#### **GROUP 2 NNFL EFFORT BREAKDOWN**

A Group 2 country's nuclear fuel cycle capability and associated nuclear material holdings are relatively small as they include only uranium mining and milling. Since many Group 2 countries have large mining operations, they will have associated technical capabilities, some within the commercial sector, to analyze samples. This capability would allow Group 2 countries to conduct nuclear material analyses domestically, albeit with limited expertise and facilities. As many mines are independently owned and operated, Group 2 countries could focus on cooperative measures to obtain existing data, e.g., non-disclosure agreements, before conducting additional analyses. The relatively low sensitivity of much of the associated with mining and milling, as well as the limited types of materials should allow group 2 countries to acquire and organize information relatively easily. The relatively low sensitivity of the information also lessens data security requirements.

#### **GROUP 3 NNFL EFFORT BREAKDOWN**

Group 3 countries do not have complex nuclear fuel cycles but have the potential to possess a large amount of nuclear material in the form of fresh and irradiated nuclear fuel and nuclear waste. A large number of a Group 3 country's nuclear fuel cycle activities are conducted in agreement with other countries, i.e., the Group 3 country receives equipment and materials from another country. Although Group 3 countries may source much of the information they need from suppliers, suppliers may be unwilling to share complete analyses of materials due to commercial sensitivities in the absence of a non-disclosure agreement. The NNFL for a Group 3 country could be arranged to reference suppliers rather than containing the analytical information and the POC for a Group 3 country could refer to analyses provided by suppliers. Group 3 countries will frequently have educational and research institutions associated with research and power reactors, providing the capability to analyze nuclear material without additional investment. The need to include information associated with nuclear research and power generation as well as the variety of different materials should allow Group 3 countries to acquire and organize information without serious complications. The sensitivity of this information is likely to require a modest level of data security.

#### **GROUP 4 NNFL EFFORT BREAKDOWN**

A Group 4 country's nuclear fuel cycle, associated nuclear materials and scientific establishment are comparable to those of a Group 3 country. Like a Group 3 country, much of the nuclear fuel cycle activities are conducted in agreement with other countries, i.e., a Group 4 country may receive equipment and materials from another country. Although Group 4 countries could source much of the information from suppliers, suppliers may be unwilling to share full analyses due to commercial sensitivities in the absence of a non-disclosure agreement. The NNFL for a Group 4 country could be arranged to reference suppliers rather than containing the analytical information and the POC for a Group 4 country could refer to analyses provided by suppliers. The NNFL POC would refer to the NNFL in the event of interdiction and allocate appropriate resources to identify the material. As Group 4 countries have more advanced nuclear fuel cycle capabilities than Group 2 and Group 3 countries, they will frequently have educational

and research institutions associated with research and power reactors, providing the capability to analyze nuclear material. The need to include information associated with nuclear research and power generation as well as the variety of different materials should allow Group 4 countries to acquire and organize information with only modest complexity. The sensitivity of the information is likely to require a fairly sophisticated data security system.

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<sup>i</sup> "International Conference on Nuclear Security: Enhancing Global Efforts Ministerial Declaration." July 5, 2013. Vienna: International Atomic Energy Agency, 2013. [http://www.iaea.org/newscenter/statements/ministerial\\_declaration.pdf](http://www.iaea.org/newscenter/statements/ministerial_declaration.pdf)

<sup>ii</sup> "Statement of Principles." United States of America Department of State. July 6, 2009. <http://www.state.gov/t/isn/rls/other/126995.htm>

<sup>iii</sup> "Work Plan of the Washington Nuclear Security Summit." Nuclear Security Summit 2014. April 13, 2010. [https://www.nss2014.com/sites/default/files/documents/12.work\\_plan.pdf](https://www.nss2014.com/sites/default/files/documents/12.work_plan.pdf).

<sup>iv</sup> "Development of a National Nuclear Forensics Library Draft Implementing Guide." International Atomic Energy Agency. February 2013. <http://www-ns.iaea.org/downloads/security/security-series-drafts/implement-guides/nst018.pdf>

<sup>v</sup> "Nuclear Fuel Cycle Information System." International Atomic Energy Agency. 2012. <http://infcis.iaea.org/NFCIS/Facilities.cshtml>.

<sup>vi</sup> "Development of a National Nuclear Forensics Library Draft Implementing Guide." International Atomic Energy Agency.

<sup>vii</sup> Robel, Martin. "Theory and Application of the Internet Discriminant Analysis Verification Engine for the U-Sourcing Database Project." Lawrence Livermore National Laboratory. June 2, 2010. <http://www.jaea.go.jp/04/np/activity/2010-10-05/2010-10-05-21.pdf>

<sup>viii</sup> "Development of a National Nuclear Forensics Library Draft Implementing Guide." International Atomic Energy Agency.

<sup>ix</sup> Development of a National Nuclear Forensics Library Draft Implementing Guide." International Atomic Energy Agency.